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(54) **Alignment adjusting system for use in optical system of optical transceiver**

Ausrichtungseinstellsystem zur Verwendung in einem optischen Sende- und Empfangssystem

Système de réglage d'alignement pour l'utilisation dans un système d'émetteur-récepteur optique

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(73) Proprietor: ATR OPTICAL AND RADIO
COMMUNICATIONS RESEARCH
LABORATORIES
Kyoto 619-02 (JP)

(72) Inventor: Arimoto, Yoshinori, 304, Kokubunji
Kokubunji-Shi, Tokyo 185 (JP)

(74) Representative: Selting, Günther, Dipl.-Ing. et al
Patentanwälte
von Kreisler-Selting-Werner,
Bahnhofsvorplatz 1 (Deichmannhaus)
50667 Köln (DE)

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Description

The present invention relates to an alignment adjusting system for use in an optical system of an optical transceiver, in particular, which is used for intersatellite communications.

Conventionally, optical communications using a beam of laser light have the following features:

- (a) since the wavelength of the laser light is smaller than one thousandth that of the microwave, antennas and transceivers can be downsized;
- (b) since a wider frequency band can be used, communications with a larger capacity can be performed in a higher speed; and
- (c) since sharp laser beams are used, mutual interference among them can be neglected.

However, to make the best use of the above features, it is necessary to direct sharper laser beam to an antenna of the destination station with higher accuracy. For example, in an optical communication between a geostationary satellite and a low-earth-orbiting satellite, it is necessary to provide an optical antenna having an aperture diameter aperture of about 20 cm. When a conventionally used semiconductor laser light with a wavelength of 0.83 μm is used, the half-width of a beam of transmitting laser light becomes approximately 5 micro-radian. In this case, pointing and tracking with an accuracy of 1 micro-radian or less is required to maintain a stable optical communication. Further, for an optical transceiver to be provided in a low-earth-orbiting satellite, it is necessary to provide a wider directivity range over 2π steradian or more in solid angle in the sphere.

In a conventional pointing and tracking system, in order to simultaneously obtain a wider angle range and a higher tracking accuracy, there has been used a control system having a double feedback loop, comprising:

- (a) a coarse tracking system having a relatively slow response speed but having a wider field of view, wherein the coarse tracking system comprises a CCD sensor, and two-axes gimbals for controlling an optical antenna with two directions; and
- (b) a fine tracking system having a narrower field of view but having a higher speed response, wherein the fine tracking system comprises a quadrant detector sensor (hereinafter, referred to as a QD sensor) composed of four photodiode cells divided into four quadrants, and a fine pointing mirror module (hereinafter, referred to as an FPM).

Such a system is disclosed in SPIE Proceedings ECO2, OPTICAL SPACE COMMUNICATION, vol. 1131, 24 April 1989, PARIS, FRANCE, pages 10-23, M. FITZMAURICE et al. "NASA/GSFC Program in Direct Detection Optical Communications for Intersatellite Links". The incoming laser beam is reflected to the telescope by a gimbal plate. The telescope is of a center-fed cassegrain type with fixed main mirror and fixed sub-mirror. The beam is split downstream in the optical path. One part of the beam is guided to a CCD camera and the second part is guided via a movable VPS lens to a quadrant detector sensor. According to the signal of the CCD camera, a coarse tracking loop is employed to adjust the laser beam to the center of the CCD camera by slewing the gimbal. After the laser beam is centered, the CCD camera is removed from the control loop and a controller, which is inputted by the quadrant detector sensor, controls the coarse tracking system and a fine tracking system which is moving the VPS lens.

Besides, a conventional center-fed cassegrain type optical antenna comprises a main mirror consisting of a concave parabolic mirror, and a submirror consisting of a convex hyperbolic mirror. In the center-fed cassegrain type optical antenna, after a beam of transmitting laser light outputted from an optical transceiver is led to the submirror through a hole formed in the center of the main mirror, the beam of laser light is reflected by the submirror, and then is reflected by the main mirror. Thereafter, the beam of transmitting laser light is transmitted to an optical antenna of a destination station.

Further, in a conventional pointing, acquisition and tracking control system, the initial acquisition is performed by receiving a beacon light having a wider field of view transmitted from a satellite of a destination station. In this case, a CCD sensor is used as the acquisition sensor, and then an error from the tracking center of the luminescent spot of the beacon light which is outputted from the CCD sensor is detected. Thereafter, based on the detected error, the two-axes gimbals mechanically connected with the optical antenna are controlled to be driven, so that the optical antenna is directed to the satellite of the destination station. The beacon light is then captured within the field of view of the QD sensor, and thereafter, tracking errors in two directions perpendicular to each other are detected based on a relative ratio of amounts of light incident on the respective photodiode cells of the QD sensor. Based on the tracking errors, the driving mechanism of the FPM is controlled to be driven so that a beam of laser light transmitted from the satellite of the destination station is captured within the field of view of a receiving photodiode sensor (hereinafter, photodiode sensor will be referred to as a PD sensor). Further, a point-ahead mirror module (hereinafter, referred to as a PAM) is used to correct a point-ahead angle of a beam of transmitting laser light so as to be substantially zero, namely, to accurately illuminate the destination station, which will be described in detail later. Then, a beam of laser light is trans-

mitted in the corrected direction toward the optical antenna of the destination station, and then the optical communication is started.

To maintain the tracking accuracy under severe environments such as a large vibration at the launching of the satellite, a large variation in the ambient temperature, so that optical communication can be carried out, it is necessary to provide 1 μm or less alignment accuracy for arrangement of devices of the optical system including mirrors and lenses. For this reason, conventionally, by using Invar (trademark: Ni-based alloy) or Zerodur (trademark: glass ceramic material), each of which has a small thermal expansion coefficient and has established performance results as a material constituting precision optical equipment, such design has been implemented that arrangement of optical devices will not change due to change in temperature.

However, there have been such problems that the above-mentioned Invar has a relatively large specific gravity while the above-mentioned Zerodur encounters difficulty in processing the same into a complex shape.

Suited for structural materials for optical transceiver to be provided in the satellite are light-weight metal materials with a specific gravity as small as possible and a thermal conductivity as large as possible, such as Al, Mg, Be or the like. However, the light-weight metal materials, in general, have relatively large thermal expansion coefficients, respectively, and therefore, it is necessary to provide an alignment adjustment mechanism for compensating for alignment errors in equipment arrangement due to thermal expansion in order to achieve optical communications. However, there has been provided no proper method for adjusting alignment of the optical transceiver after launching of the satellite. Even if such adjustment is made possible in some way, severe demand for accuracy would cause the optical transceiver provided comprising an optical antenna to be relatively large sized because of the provision of the alignment adjustment mechanism, disadvantageously.

An essential object of the present invention is therefore to provide an alignment adjusting system for use in an optical system of an optical transceiver, having a smaller size and a smaller weight than those of the conventional apparatuses, and being capable of adjusting the arrangement of the optical system with higher accuracy.

In order to achieve the aforementioned objective, according to one aspect of the present invention, there is provided an alignment adjusting system for use in an optical system in an optical transceiver, comprising:

an optical antenna having a main mirror and a submirror, both of which being provided around an optical axis of said optical antenna and away from each other by a predetermined interval, said optical antenna transmitting a beam of transmitting light outputted from said optical transceiver to an optical antenna of a destination station after sequentially reflecting said beam of transmitting light by said submirror and said main mirror;
 an optical coupling means for optically coupling said optical antenna to said optical transceiver;
 a return-reflection mirror for return-reflecting a part of said beam of transmitting light, said return-reflection mirror being provided in either one of said main mirror and said submirror;
 first detection means for detecting a defocusing amount of said beam of transmitting light in said optical antenna, in response to said beam of transmitting light return-reflected by said return-reflection mirror;
 first moving means for moving said submirror in a direction parallel to the optical axis of said optical antenna; and
 first control means for controlling said first moving means so that the defocusing amount of said beam of transmitting light becomes substantially zero, in response to a defocusing amount of said beam of transmitting light in said optical antenna which is detected by said first detection means.

By the arrangement of the above-mentioned invention, when the reflection mirror for return-reflecting a beam of transmitting light is provided in the main mirror, the defocusing amount of the beam of transmitting laser light can be corrected so as to be substantially zero over the optical system from the optical transceiver through the optical coupling or connection means to the submirror and the main mirror of the optical antenna. On the other hand, when the reflection mirror for return-reflecting a beam of transmitting light is provided in the submirror, the defocusing amount of the beam of transmitting laser light can be corrected so as to be substantially zero over the optical system from the transceiver through the optical coupling or connection means to the submirror of the optical antenna. As a result, the size of the alignment adjusting system for use in the optical system in the optical transceiver of the present invention can be made smaller and the weight thereof can be made smaller than those of the conventional apparatuses, and further the present invention is capable of adjusting arrangement of the optical system located from the optical transceiver through the optical coupling or connection means to the submirror or the main mirror of the optical antenna with a higher accuracy. The provision of the alignment adjusting system allows the main mirror and the submirror to be made of light-weight metal materials each having a relatively smaller specific gravity and a relatively larger thermal conductivity, such as Al, Mg, Be or the like. Accordingly, the weight of the satellite in which the optical transceiver is provided can be advantageously and remarkably reduced.

Further, in the above-mentioned alignment adjusting system, said optical antenna sequentially reflects a beam of received light received from said optical antenna of said destination station by said main mirror and said submirror, and thereafter, outputs said beam of reflected light to said optical transceiver through said optical coupling means; and

said alignment adjusting system further comprising:

second detection means for detecting a deviation amount of said beam of transmitting light from the optical axis of said optical antenna, in response to said beam of transmitting light return-reflected by said return-reflection mirror;

third detection means for detecting a deviation amount of said beam of received light from the optical axis of said optical antenna in response to said beam of received light reflected by said submirror;

second moving means for moving the optical axis of said beam of transmitting light transmitting in said optical coupling means, said second moving means being provided in said optical coupling means; and

second control means for controlling said second moving means so that the deviation amount of said beam of transmitting light from the optical axis of said optical antenna coincides with the deviation amount of said beam of received light from the optical axis of said optical antenna, in response to the deviation amount of said beam of transmitting light from the optical axis of said optical antenna which is detected by said second detection means and the deviation amount of said beam of received light from the optical axis of said optical antenna which is detected by said third detection means.

By the arrangement of the above-mentioned invention, when the reflection mirror for return-reflecting a beam of transmitting laser light is provided in the main mirror, the deviation amount of the beam of transmitting light from the optical axis of the optical system can be corrected so that the optical axis coincides with that of the beam of received light, over the optical system from the optical transceiver through the optical coupling or connection means to the submirror and the main mirror of the optical antenna. On the other hand, when the reflection mirror for return-reflecting a beam of transmitting light is provided in the submirror, the deviation amount of the beam of transmitting laser light from the optical axis of the optical system can be corrected so that the optical axis of the beam of transmitting light coincides with that of the beam of received light, over the optical system from the optical transceiver through the optical coupling or connection means to the submirror of the optical antenna. Accordingly, the size of the alignment adjusting system for use in the optical system in the optical transceiver of the present invention can be made smaller and the weight thereof can be made smaller than those of the conventional apparatuses, and further the present invention is capable of adjusting arrangement of the optical system from the optical transceiver through the optical coupling or connection means to the submirror or the main mirror of the optical antenna with a higher accuracy.

Further, in the above-mentioned alignment adjusting system, said main mirror is either one of a ring-shaped concave parabolic mirror and a ring-shaped concave nearly-parabolic hyperbolic mirror;

said return-reflection mirror is either one of a ring-shaped concave spherical mirror and a ring-shaped concave nearly-spherical elliptical mirror, said return-reflection mirror being formed integrally together with said main mirror and concentrically with said main mirror around the optical axis of said optical antenna; and
said main mirror and said return-reflection mirror are arranged so that a focal point of said main mirror coincides with the center of curvature of said return-reflection mirror.

Still further, in the above-mentioned alignment adjusting system, said main mirror is provided on an outer periphery of a ring-shaped body, while said return-reflection mirror is provided on an inner periphery of said ring-shaped body, and
said return-reflection mirror has an optical through hole for passing said beam of transmitting light and said beam of received light therethrough, said optical through hole having a center coinciding with the optical axis of said optical antenna, said optical through hole being formed so as to be concentric with said main mirror around the optical axis of said optical antenna.

Still more further, in the above-mentioned alignment adjusting system, said submirror is a convex hyperbolic mirror, and

said return-reflection mirror is either one of a concave spherical mirror and a concave nearly-spherical elliptical mirror which is formed integrally and concentrically with said submirror around the optical axis of said optical antenna.

These and other objects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings throughout which like parts are designated by like reference numerals, and in which:

Fig. 1 is a schematic block diagram showing an optical transceiver together with an optical antenna and an adjusting system for an optical system of the optical transceiver of a preferred embodiment according to the present invention;

Fig. 2 is a longitudinal cross-sectional view showing details of the optical antenna shown in Fig. 1;

Fig. 3 is a front view of an optical detection surface of a CCD sensor shown in Fig. 1;

Fig. 4 is a front view of an optical detection surface of a QD sensor shown in Fig. 1;

Fig. 5 is a longitudinal cross-sectional view of a convex parabolic mirror showing an action thereof;

Fig. 6 is a longitudinal cross-sectional view of a convex spherical mirror showing an action thereof;

Fig. 7 is a longitudinal cross-sectional view of a main mirror of an optical antenna of the present invention comprising a convex parabolic mirror and a convex spherical mirror;

Fig. 8 is a flowchart of a control flow showing an alignment adjusting process which is executed by the adjusting system for the optical system of the optical transceiver shown in Fig. 1; and

Fig. 9 is a graph showing a relative sensitivity on a reciprocal of a wavefront radius in the preferred embodiment according to the present invention.

A preferred embodiment according to the present invention is described hereinbelow with the accompanying drawings.

Fig. 1, showing a preferred embodiment of the present invention, is a schematic block diagram of an optical transceiver comprising an optical antenna 10 and an alignment adjusting system for an optical system for use in optical communications.

The center-fed cassegrain type optical antenna 10 of the present preferred embodiment, as shown in Fig. 2, comprises the followings:

(a) a main mirror or reflector 1 comprising a ring-shaped concave parabolic mirror 1a for transmitting and receiving beams of lights, and a ring-shaped concave spherical return-reflection mirror or retroreflector 1b for turn-around-reflecting, retroreflecting or return-reflecting a beam of transmitting laser light, both of which are provided concentrically around an optical axis CL of the beam of laser light, the parabolic mirror 1a being provided on the outer periphery of the main mirror 1, the concave spherical return-reflection mirror 1b being provided on the inner periphery of the main mirror 1 and having an optical through hole 1h in the center of the concave spherical return-reflection mirror 1b, and both of the parabolic mirror 1a and the spherical return-reflection mirror 1b being formed integrally with each other; and

(b) a submirror or subreflector 2 made of a convex hyperbolic mirror provided at a position shifted from the coincident position of the focal point Fp of the parabolic mirror 1a and the center of curvature Rc of the spherical return-reflection mirror 1b (for reference characters Fp and Rc, See Fig. 7) toward the main mirror 1 around the optical axis CL.

In the center-fed cassegrain type optical antenna 10, a beam of transmitting laser light outputted from the optical transceiver is led to the submirror 2 through the optical through hole 1h, and then is sequentially reflected by the submirror 2 and the parabolic mirror 1a of the main mirror 1. Thereafter, a beam of transmitting laser light is transmitted to an optical antenna of a destination station. On the other hand, a beam of transmitting laser light which has been reflected by the submirror 2 is reflected by the spherical return-reflection mirror 1b of the main mirror 1, so as to be returned toward the submirror 2, and then is reflected again by the submirror 2 so as to be incident toward the optical transceiver. Then, based on the beam of returned transmitting laser light (hereinafter, referred to as a beam of returned transmitting laser light), an alignment adjustment for the optical system in the optical transceiver is performed.

In the present preferred embodiment, it is noted that the wavelength of the beam of the transmitting light outputted from a laser diode 37 is slightly different from the wavelength of the beam of received light which is transmitted from the optical transceiver of the destination station and is received by the optical antenna 10 in such a degree that they can be separated by respective optical filters provided in a CCD sensor 30 and a QD sensor (quadrant detector sensor) 32.

Referring to Fig. 2, in the center-fed cassegrain type optical antenna 10, the ring-shaped parabolic mirror 1a for transmitting and receiving beams of laser lights is provided on the outer periphery of the main mirror 1 so as to oppose to the submirror 2, namely, so as to be formed on the surface of the main mirror 1 located on the side toward the direction of reception and transmission of the optical antenna 10. Further, the ring-shaped concave spherical return-reflection mirror 1b for return-reflecting a beam of transmitting laser light, in which an optical through hole 1h of a circular shape is formed having the center the optical axis CL passes through, is provided on the inner periphery of the main mirror 1 so as to oppose to the submirror 2, namely, so as to be formed on the surface of the main mirror 1 located on the side toward the direction of reception and transmission of the optical antenna 10.

In the optical antenna 10, the position of the focal point Fp of the parabolic mirror 1a and the position of the center of curvature Rc of the spherical return-reflection mirror 1b are located at a point (referred to as a coincident point $Fp = Rc$ hereinafter) so as to coincide with each other. Further, the submirror 2 made of the convex hyperbolic mirror is provided at a position shifted from the coincident position $Fp = Rc$ on the side toward a concave reflection surface of the main mirror 1, for example, See Fig. 7. In the present preferred embodiment, the centers of curvatures of the mirrors 1a and 1b are so set as to be different from each other, and further, a ratio f_p/f_c of the focal length f_p of the parabolic mirror 1a to the focal length f_c of the spherical return-reflection mirror 1b is preferably set to a value slightly smaller than 2.

As each of the materials for the main mirror 1 and the submirror 2, optical glass is preferably used, such as the

Zerodur or the like, having a relatively smaller thermal expansion coefficient. However, when the alignment adjusting system according to the present invention is provided, this allows the use of light-weight metal materials, such as Al, Mg, Be or the like, having a relatively smaller specific gravity and a relatively larger thermal conductivity, in the application of mounting the alignment adjusting system onto a satellite.

Further, if the two mirrors, that is parabolic mirror and spherical return-reflection mirror, are processed simultaneously by an ultra high-precision machining, mis-alignment between the two mirrors is negligibly small and this good alignment accuracy will be maintained after these mirrors are launched in the space because the above-mentioned larger thermal conductivity will minimize the thermal deformation of the mirrors.

In general, the shape of the mirror surface of the optical antenna 10 can be approximated by an axially symmetrical quadratic surface. Assuming that the radius at any given position of the mirror surface from the optical axis is ρ , the curvature of the center of the quadratic surface is C , and the deformation parameter representing the shape of the quadratic surface is K , then the depth of mirror surface Sag from the intersection (vertex) between the quadratic surface and the optical axis of the mirror surface can be represented by the following equation (1):

$$Sag = (C \cdot \rho^2) / \{1 + (1 - C^2 \rho^2 K)^{1/2}\} + a_6 \rho^6 + a_8 \rho^8 + a_{10} \rho^{10} + \quad (1),$$

where a_6 to a_{10} are coefficients representing higher-order aspherical surfaces, and further the deformation parameter K has the following meanings:

- (a) If $K < 0$, then the mirror surface of the main mirror 1 becomes a hyperbolic surface;
- (b) If $K = 0$, then the mirror surface of the main mirror 1 becomes a parabolic surface;
- (c) If $0 < K < 1$, then the mirror surface of the main mirror 1 becomes an elliptical surface;
- (d) If $K = 1$, then the mirror surface of the main mirror 1 becomes a spherical surface; and
- (e) If $K > 1$, then the mirror surface of the main mirror 1 becomes an elliptical surface.

For example, when the main mirror 1 is provided comprising only a parabolic mirror 51 having a focal length f_p of 30 as shown in Fig. 5, like a conventional optical antenna, a beam of transmitting light transmitted from the focal point F_p toward the parabolic mirror 51 is reflected by the parabolic mirror 51, and then, the transmitting light becomes collimated parallel light, which is then transmitted to the optical antenna of the destination station.

On the other hand, when the main mirror 1 is provided comprising only a spherical mirror 52 with a focal length f_p of 30 as shown in Fig. 6, a beam of transmitting light transmitted from the center of curvature R_c of the spherical mirror 52 toward the spherical mirror 52 is reflected by the spherical mirror 52, and then, it is returned to the center of curvature R_c along the same optical path.

In the present preferred embodiment, as shown in Fig. 7, the main mirror 1 has not only a parabolic mirror 51 provided on the outer periphery side of the main mirror 1 but also a spherical mirror 52a provided on the inner periphery side of the main mirror 1. In the preferred embodiment of Fig. 7, the focal length f_p of the parabolic mirror 51 is equal to 30, and the focal length f_p thereof is set to be slightly larger than the focal length f_c of the spherical mirror 52a equal to 15. In this case, a beam of transmitting light transmitted from the coincident position $F_p = R_c$ of the focal point F_p and the center of curvature R_c toward the parabolic mirror 51 and the spherical mirror 52a is reflected by the parabolic mirror 51, and then, the transmitting light becomes a collimated parallel light, which is then transmitted toward the optical antenna of the destination station. The transmitting light is further reflected by the spherical mirror 52a, and thereafter, it is returned to the center of curvature R_c along the same optical path. The returned transmitting light is used as a reference optical signal for the alignment adjustment for the optical system in the optical transceiver, as described in detail later.

Further, in the optical antenna 10, a submirror driving mechanism 2d which has been known to those skilled in the art is provided on the rear surface of the submirror 2 being opposite to the mirror surface of the submirror 2. In response to a control signal from an MPU (microprocessing unit) 20, the submirror driving mechanism 2d moves the submirror 2 in a direction parallel to the optical axis CL coincident with the center axis of the optical antenna 10 which is the Z-axis direction of Figs. 1 and 2 (hereinafter, referred to as a Z-axis direction of the optical antenna 10), and further moves the submirror 2 in two axial directions orthogonal to each other and perpendicular to the optical axis CL , wherein the two axial directions have an origin of the mirror center of the submirror 2. One of the two axial directions is, as shown in Figs. 1 and 2, a X-axis direction (referred to as an X-axis direction hereinafter) perpendicular to the paper surface of the drawings, and another one thereof is a Y-axis direction (referred to as a Y-axis direction hereinafter) defined on the paper surface of the drawings.

Further, in the optical antenna 10, two-axes gimbals 1d are provided, the angle of which is changed in response to a control signal from the MPU 20, with the two axes in two directions orthogonal to each other which respectively

correspond to the X-axis direction and the Y-axis direction of the optical antenna 10 and are parallel to the X-axis direction and the Y-axis direction thereof. Still further, the optical antenna 10 is provided with a hood 3 having a cylindrical shape concentric with the optical axis CL of the optical antenna 10, wherein the hood 3 is formed so as to cover the inner mirror surface of the main mirror 1 and the entire submirror 2, for the purpose of preventing unnecessary signal light from being incident into the inside of the optical antenna 10.

As shown in Fig. 2, the optical system for optically connecting the optical transceiver and the optical antenna 10 comprises the followings:

- (a) an eyepiece 4 composed of a single-convex lens 4 and a double-convex lens 4b;
- (b) an FPM (fine pointing mirror module) 11;
- (c) three beam splitters 12, 13 and 14; and
- (d) a PAM (point-ahead mirror module) 15.

The FPM 11 is provided for reflecting a beam of transmitting laser light and a beam of received light so that a beam of returned transmitting light sent from the eyepiece 4 is incident onto a reflecting mirror of the FPM 11 at an incident angle of 45° and then goes out at an outgoing angle of 45° so as to be incident into the beam splitter 12. In the FPM 11, a direction passing through the intersection between the mirror surface of the reflection mirror of the FPM 11 and the optical axis CL and being perpendicular to the paper surface of Fig. 1 is defined as a Y-axis of the FPM 11, while a direction located on the mirror surface of the reflection mirror of the FPM 11 and perpendicular to the Y-axis is defined as an X-axis of the FPM 11. The FPM 11 comprises a driving mechanism (not shown) for rotating the mirror surface of the reflection mirror thereof around the X-axis and Y-axis of the FPM 11 in response to a control signal sent from the MPU 20.

Further, the PAM 15 is provided for reflecting a beam of transmitting light so that a beam of transmitting light generated and transmitted from the laser diode 37 is incident onto a reflection mirror of the PAM 15 at an incident angle of 45° and then goes out at an outgoing angle of 45° so as to be incident into the beam splitter 14. In the PAM 15, a direction passing through the intersection between the mirror surface of the reflection mirror of the PAM 15 and the optical axis CL and being perpendicular to the paper surface of Fig. 1 is defined as a Y-axis of the PAM 15, while a direction located on the mirror surface of the reflection mirror of the PAM 15 and perpendicular to the Y-axis is defined as an X-axis of the PAM 15. The PAM 15 comprises a driving mechanism (not shown) for rotating the mirror surface of the reflection mirror thereof around the X-axis and Y-axis of the PAM 15 in response to a control signal sent from the MPU 20.

In the optical antenna 10, a beam of receiving light received by the optical antenna 10 is reflected by the parabolic mirror 1a of the main mirror 1 and then is directed toward the submirror 2, which then reflects the beam of received light. The beam of received light reflected by the submirror 2 transmits toward the eyepiece 4 approximately in a direction parallel to the optical axis CL.

The beam of received light and the above-mentioned beam of returned transmitting light are incident onto the FPM 11 through the eyepiece 4, and then are reflected by the reflection mirror of the FPM 11. Thereafter, these lights are incident into the beam splitter 12. The beam splitter 12 divides these incident lights into two beams of lights, one of which (referred to as a beam of first light hereinafter) passes through the beam splitter 12 as it is, and another one of which (referred to as a beam of second light hereinafter) is reflected and extracted. A beam of second light reflected by the beam splitter 12 is incident into the CCD sensor 30, while a beam of first light passing through the beam splitter 12 is incident into the next beam splitter 13.

Then the beam splitter 13 divides the incident light into two beams of lights, one of which (referred to as a beam of third light hereinafter) passes through the beam splitter 13 as it is, and another one of which (referred to as a beam of fourth light hereinafter) is reflected and extracted. A beam of fourth light reflected by the beam splitter 13 is incident into the QD sensor 32, while a beam of third light passing through the beam splitter 12 is incident into the next beam splitter 14. Further, the beam splitter 14 then reflects the beam of light incident from the beam splitter 13, and makes the beam of reflected light be incident into a PD sensor (photodiode sensor) 34.

On the other hand, a modulator 36 modulates the transmitting light having a predetermined transmitting wavelength by a predetermined modulation method such as an intensity modulation according to a transmission base band signal inputted from an external apparatus, and then a beam of modulated transmitting light is outputted from the laser diode 37. The beam of modulated transmitting light is reflected by the reflection mirror of the PAM 15, and thereafter, passes sequentially through the three beam splitters 14, 13 and 12, then is incident onto the reflection mirror of the FPM 11. Thereafter, the beam of transmitting light is reflected by the reflection mirror of the FPM 11, and then is projected through the eyepiece 4 onto the submirror 2 of the optical antenna 10.

The CCD sensor 30, as shown in Fig. 3, has a square-shaped photo-detector plane consisting of an X-axis and a Y-axis corresponding to the X-axis and the Y-axis of the optical antenna 10, respectively. The photo-detector plane of the CCD sensor 30 comprises a plurality of photo-detector cells located at predetermined equal intervals so as to be

parallel to the X-axis and the Y-axis, wherein each photo-detector cell is labeled with X and Y coordinates on a plane in a shape of a predetermined grating. The CCD sensor 30 further comprises two band-pass filters (not shown), one of which passes therethrough only the above-mentioned beam of returned transmitting light among the incident lights, and another one of which passes therethrough only the above-mentioned beam of received light among the incident light, namely, the beam of returned transmitting light is separated from the beam of received light. Thereafter, the beam of separated returned transmitting light is detected by the respective photo-detector cell and then is converted into an electric signal, which is outputted to a CCD processing circuit 31, while the beam of separated received light is detected by the respective photo-detector cell and then is converted into an electric signal, which is outputted to the CCD processing circuit 31.

In response to the respective electric signals sequentially outputted from the CCD sensor 30, the CCD processing circuit 31 calculates not only geometrical time-average radius of an image of the beam of returned transmitting light obtained on the photo-detector plane of the CCD sensor 30 but also the maximum value in the light intensity distribution thereof, and then outputs these calculated data to the MPU 20. With respect to the beam of received light, in response to the respective electric signals sequentially outputted from the CCD sensor 30, the CCD processing circuit 31 further outputs to the MPU 20 an error signal representing the amounts of errors in the X-axis direction and the Y-axis direction from the origin O of Fig. 3 corresponding to the optical axis CL. In this case, the data of the time-averaged radius of the image and the maximum value of the intensity of the beam of returned transmitting light includes information of a defocusing amount of the beam of transmitting light in the optical antenna 10.

Meanwhile, in response to the error signal of the beam of received light outputted from the CCD processing circuit 31, the MPU 20 controls the two-axes gimbals 1d so that the beam direction of the optical antenna 10 is directed toward the direction of the optical antenna of the destination station. Further, in the alignment adjustment process which will be described in detail later, the MPU 20 controls the submirror driving mechanism 2d in response to the data of the time-average radius of the beam of returned transmitting light and the maximum value of the distribution of the light intensity thereof which are outputted from the CCD processing circuit 31, so that the inputted time-average radius becomes the minimum value and also the submirror 2 moves forward or backward in the Z-axis direction of the optical antenna 10. This leads to correction of the defocusing amount of the beam of transmitting light, resulting in no defocusing amount of the beam of transmitting light, namely, in-focus state on the beam of transmitting light. If there is an extremely large defocusing amount of the beam of transmitting light, it is impossible to completely set the in-focus state thereon only by adjustment of the position of the submirror 2 in the Z-axis direction. Therefore, in this case, although not shown, the eyepiece 4 is moved forward or backward in a direction parallel to the optical axis CL by a driving mechanism (not shown) which has been known to those skilled in the art, so that the defocusing amount of the beam of transmitting laser light is corrected, resulting in the in-focus state.

Further, the QD sensor 32, as shown in Fig. 4, comprises four photodiode cells PA1 to PA4, which are obtained by dividing the sensor surface of the QD sensor 32 into four quadrants with boundary lines of an X-axis and a Y-axis corresponding to the X-axis and the Y-axis of the optical antenna 10, respectively. The first, second, third and fourth quadrant cells are here denoted by PA1, PA2, PA3 and PA4, respectively, as seen from the front side of the QD sensor 32. Each of the photodiode cells PA1 to PA4 comprises two band-pass filters (not shown), one of which passes therethrough only the above-mentioned beam of returned transmitting light among the incident lights, and another one of which passes therethrough only the above-mentioned beam of received light among the incident light, namely, the beam of returned transmitting light is separated from the beam of received light. Thereafter, the beam of separated returned transmitting light is detected by the first group of photodiode cells PA1 to PA4 and then is converted into the first group of electric signals V1 to V4 respectively for the first group of four photodiode cells PA1 to PA4, which are outputted to a QD processing circuit 33, while the beam of separated received light is detected by the second group of photodiode cells PA1 to PA4 and then is converted into the second group of electric signals V1 to V4 respectively for the second group of four photodiode cells PA1 to PA4, which are outputted to the QD processing circuit 33.

In response to the inputted first and second groups of electric signals V1 to V4 with respect to the beam of returned transmitting laser light and the beam of the received light, the QD processing circuit 33 calculates tracking error data δx and δy , each representing not only the direction and the amount of deviation or distance from the optical axis CL (respectively referred to as direction and amount of an axial deviation hereinafter), and then the QD processing circuit 33 outputs the calculated tracking error data δx and δy to the MPU 20. The tracking error data δx and δy are represented by the following equations (2) and (3):

$$\delta x = \{(V1+V4) - (V2+V3)\} / (V1+V2+V3+V4) \quad (2),$$

and

$$\delta y = \{(V1+V2) - (V3+V4)\} / (V1+V2+V3+V4) \quad (3),$$

for both of the beam of transmitting light and the beam of received light.

In response to the tracking error data δx and δy of the beam of received light outputted from the QD processing circuit 33, the MPU 20 controls the driving mechanism of the FPM 11 so that a beam of receiving light transmitted from the optical antenna of the destination station can be captured within a predetermined receiving field of view of the PD sensor 34. Further, in the alignment adjustment process which will be described in detail later, in response to the tracking error data δx and δy of the beam of returned transmitting light outputted from the QD processing circuit 33, the MPU 20 controls the driving mechanism of the PAM 15 so that the tracking error data δx and δy of the beam of returned transmitting light coincide with the tracking error data δx and δy of the beam of received light, respectively, and further the mirror surface of the PAM 15 rotates around the X-axis and Y-axis of the PAM 15.

In the pointing, acquisition and tracking system for the optical transceiver with the above-described arrangement, an initial acquisition is performed by receiving a beacon light having a relatively wider field of view which is transmitted from the satellite of the destination station. In this initial acquisition process, the control system detects an error from the tracking center of the luminescent spot of the beacon light outputted from the CCD sensor 30, and then controls the two-axes gimbals 1d coupled with the optical antenna 10 in response to the detected error, so as to direct the beam direction of the optical antenna 10 toward the direction of the satellite of the destination station. Thus, the beacon light is captured within the predetermined field of view of the QD sensor 32, and thereafter, an tracking error in the two directions perpendicular to each other is detected from relative ratios of amounts of lights incident onto the respective photodiode cells of the QD sensor 32. Then, based on the detected tracking error, the control system controls the driving mechanism of the FPM 11 to capture a beam of light transmitted from the satellite of the destination station within the predetermined field of view of the PD sensor 34 for receiving the same. Further, with the use of the PAM 15, a point-ahead angle, which will be described in detail later, is corrected, and then a beam of laser light is transmitted in the above-corrected direction, starting the optical communication with the satellite of the destination station.

It is noted here that the point-ahead in the optical satellite communication performed either between an earth station and a low-earth-orbiting satellite station or between a geostationary satellite station and a low-earth-orbiting satellite station is different from that in general astronomy in the following point. That is, the pointing and tracking system of the optical transceiver is designed so as to track the direction of laser light coming up from the optical antenna of the destination station. However, since the speed of light is a finite value of 300,000 km/sec, the direction of the satellite of the destination station may have changed when the direction of light sent from the optical antenna of the destination station is detected, because of the relative movement therebetween. Further, since it takes a predetermined time for a beam of transmitting light to propagate to the satellite of the destination station, this leads to a deviation of the direction, similarly. In the optical satellite communication performed between a geostationary satellite station and a low-earth-orbiting satellite station, the above-mentioned deviation of the direction becomes approximately several tens micro-radian, which is a value of an order which cannot be neglected in the laser communication involving an accurate tracking having an order of about 1 micro-radian. The point-ahead in astronomy relates to the deviation of the directions of planets as seen from the earth, namely, the deviation of the directions in uni-directional light propagation. On the other hand, in optical satellite communications, a point-ahead takes place in the bi-directional light propagation, which results in a doubled amount of correction.

Fig. 8 is a flow chart of control flow showing the alignment adjustment process executed by the alignment adjusting system for use in the optical system in the optical transceiver shown in Fig. 1. The alignment adjustment process is periodically executed by the MPU 20 thereof at predetermined equal time intervals corresponding to the time constant of change in the temperature of the optical system, for example, once every 10 minutes or the like.

Referring to Fig. 8, in step S1, in response to the tracking error data δx and δy of a beam of return-transmitting light outputted from the QD processing circuit 33, the MPU 20 controls the driving mechanism of the PAM 15 so that the tracking error data δx and δy of the beam of returned transmitting light coincide with the tracking error data δx and δy of a beam of received light, respectively, and further the mirror surface of the reflection mirror of the PAM 15 rotates around the X-axis and the Y-axis of the PAM 15. This allows the direction and amount of the axial deviation in the direction perpendicular to the optical axis of the light of transmitting laser light to be corrected, and then, which results in making the optical axis of the beam of transmitting laser light coincident with the optical axis of the beam of received light.

Then, in step S2, in response to the time-average radius data and the maximum value of the intensity of the beam of returned transmitting light outputted from the CCD processing circuit 31, the MPU 20 controls the submirror driving mechanism 2d so that the inputted time-average radius data becomes the minimum value and further the submirror 2 moves forward or backward in the Z-axis direction of the optical antenna 10. As a result, the defocusing amount of the beam of transmitting laser light can be corrected and is adjusted so that there is no defocusing amount, namely, adjusted into the in-focus state of the beam of transmitting laser light with a higher accuracy or preciseness.

Although the wavelength of the beam of transmitting light and that of the beam of received light are made different from each other in the above-mentioned preferred embodiment, the present invention is not limited to this. The wavelength of the beam of transmitting light may be set so as to be the same, substantially the same, or approximately the same as that of the beam of received light, or the wavelength of the beam of transmitting light may be set so as to be extremely close to that of the beam of received light. In this case, these beams of lights are set so that an area or a distribution of the beam of transmitting light is different from that of the beam of received light.

For example, the beam of received light substantially may set so as to exist on the outer periphery of the circular beam spot having a predetermined diameter, and the beam of transmitting light substantially may set so as to exist on the inner periphery of the circular beam spot which is not overlapped on the outer periphery thereof. In this case, in each of the CCD sensor 30 and the QD sensor 32, a shutter mechanism is provided comprising a circular inner-peripheral shutter for shielding the beam of transmitting laser light located on the inner periphery of the circular beam spot, and another ring-shaped outer-peripheral shutter for shielding the beam of received light located on the outer periphery of the circular beam spot. Then, the inner-peripheral shutter and the outer-peripheral shutter are controlled so as to be switched alternately using a time division multiplex based on a predetermined timing signal which is periodically generated. Based on the above-mentioned timing signal, the signal detected by the CCD sensor 30 and the signal detected by the QD sensor 32 are discriminated from each other, and then the discriminated signals are separately extracted. It is noted that the PD sensor 34 always extracts only the beam of received light located on the outer periphery thereof, and then converts the same into the electric signal.

In the optical antenna 10 of the above-mentioned preferred embodiment, the concave parabolic mirror 1a for transmitting and receiving beams of lights is provided on the outer periphery of the main mirror 1, while the spherical return-reflection mirror 1b having the optical through hole 1h for return-reflecting the beam of transmitting laser light is provided on the inner periphery of the main mirror 1.

Fig. 9 is a graph of a relationship between a gain of transmitting light and a gain of return-reflected transmitting light with a measure of a reciprocal of a wavefront radius [1/km] and a relative gain [dB], showing not only lowering of the relative gain of the optical antenna due to a defocusing in the present preferred embodiment, but also change in the maximum intensity of the beam of returned transmitting laser light.

An alternate long and short dash line of Fig. 9 shows a theoretical calculation result of the antenna gain with respect to the beam of transmitting laser light when an error of a circular-wavefront radius shown in the horizontal axis of Fig. 9 is generated in an aperture part of the optical antenna due to a defocusing, which is obtained with reference to the following document: Bernard J. Klein and John J. Degnan, "Optical Antenna Gain, 1:Transmitting Antennas", Applied Optics, Vol. 13, No. 9, in September, 1974, on the following assumption:

- (a) an amplitude distribution of the beam of transmitting laser light is set to a Gaussian distribution;
- (b) a diameter of an aperture of the optical antenna is set to 19 cm;
- (c) a wavelength of the transmitting laser light is set to 0.83 μm ;
- (d) a radius of the Gaussian beam in the aperture part of the optical antenna is set to 9.5 cm; and
- (e) the radius of the submirror is set to 2.25 cm.

Further, the solid line of Fig. 9 shows change in the intensity of the beam of return-reflected transmitting laser light when there is a defocusing similar to the above-mentioned amount. The ring-shaped concave spherical return-reflection mirror 1b has an outer diameter of 2.25 cm and an inner diameter of 1.55 cm. The left end of Fig. 9 corresponds to the state of no defocusing amount, namely, the in-focus state. In comparison between the in-focus state and the case where an error of the circular wavefront radius of 20 km is caused in the aperture part of the optical antenna, namely, the case of a reciprocal of a wavefront radius of 0.05 1/km, the relative gain of the optical antenna decreases by 0.92 dB, and then this corresponds to 1.2 dB lowering of the signal intensity in the CCD sensor 30 with respect to the beam of returned transmitting laser light.

Therefore, for example, if an intensity measurement of the beam of returned transmitting light in the CCD sensor 30 has a preciseness of 20 % or less, namely, -1 dB or less, the deterioration amount of the gain of the optical antenna due to defocusing of the beam of transmitting laser light can be prevented from raising more than 1 dB. This sensitivity sufficiently satisfies predetermined requirements for the optical antenna of the optical transceiver.

That is, since the detection sensitivity for the defocusing amount of the optical system is in inverse proportion to the diameter of the spherical return-reflection mirror 1b without the optical through hole 1h, providing the spherical return-reflection mirror 1b is provided on the inner periphery leads to lowering of the detection sensitivity of alignment error. However, the surface which is shielded by the submirror 2 so as to be unusable for a beam of transmitting laser light can be effectively utilized, and this allows the effective diameter of the main mirror 1 to be reduced advantageously.

Further, the concave parabolic mirror 1a for transmitting and receiving beams of lights may be provided on the inner periphery of the main mirror 1, while the spherical return-reflection mirror 1b having the optical through hole 1h for return-reflecting the beam of transmitting laser light may be provided on the outer periphery of the main mirror 1.

In the above-mentioned preferred embodiment, the center-fed cassegrain type optical antenna 10 comprising the main mirror 1 including the concave parabolic mirror 1a for transmitting and receiving beams of lights and the concave spherical return-reflection mirror 1b for return-reflecting a beam of transmitting laser light has been used, the present invention is not limited to this. However, for example, a Richey-Chréien type optical antenna may be used for the purpose of obtaining a wider tracking angle range. In such a case, in the main mirror 1, a concave hyperbolic mirror having a mirror surface close to a concave parabolic surface may be used for transmitting and receiving beams of lights, while a concave elliptic mirror having a reflection mirror close to a concave spherical mirror may be used for return-reflecting a beam of transmitting light. In this case, the deformation parameter K of the former hyperbolic mirror is preferably in a range of $-0.1 < K < 0$, and the deformation parameter K of the latter elliptic mirror is preferably in a range of $0.9 < K < 1.0$.

In the above-mentioned preferred embodiment, the main mirror 1 is provided together with a mirror surface for return-reflecting a beam of light, whereby alignment adjustment can be achieved for arrangement of the devices located over from the optical transceiver through the optical system to the submirror 2 and the main mirror 1. However, the present invention is not limited to this arrangement. A mirror surface for return-reflecting a beam of transmitting light may be provided in the submirror 2. In this case, a reflection mirror having such mirror surface for return-reflecting a beam of light is required only to be either a spherical surface or an elliptic surface close to a spherical surface, wherein the reflection mirror is provided on the inner peripheral portion or the outer peripheral portion of the submirror 2. In this modification example, the submirror 2 is a convex hyperbolic mirror, while the reflection mirror for return-reflecting a beam of light is either a concave spherical mirror or a nearly-spherical concave elliptic mirror formed integrally together with the submirror 2 and concentrically with the submirror 2 around the optical axis CL. With this arrangement, alignment adjustment can be achieved for arrangement of the devices located over the area from the optical transceiver through the optical system to the submirror 2. Furthermore, in the case where the main mirror 1 and the submirror 2 are mechanically coupled with each other and further an accurate alignment adjustment is achieved therefor, alignment adjustment can be achieved for arrangement of the devices located over the area up to the submirror 2 and the main mirror 1 through the optical system.

Although the optical antenna is used for bi-directional optical transceiver in the above-mentioned preferred embodiment, the present invention is not limited to this. The present invention may be applied to a uni-directional optical transmitter intended for only transmission or an optical broadcasting transmitter intended for only transmission.

Although the communication signals of the wavelength region of light are used in the above-mentioned preferred embodiment, the present invention is not limited to this. The present invention may be applied to transceiver or broadcasting apparatus which employ communication signals of a frequency band of microwave, semi-millimeter wave, millimeter wave, or the like.

By the arrangement of the above-mentioned preferred embodiments, when the reflection mirror for return-reflecting a beam of transmitting light is provided in the main mirror, the defocusing amount of the beam of transmitting laser light can be corrected so as to be substantially zero over the optical system from the optical transceiver through the optical coupling or connection means to the submirror and the main mirror of the optical antenna. On the other hand, when the reflection mirror for return-reflecting a beam of transmitting light is provided in the submirror, the defocusing amount of the beam of transmitting laser light can be corrected so as to be substantially zero over the optical system from the transceiver through the optical coupling or connection means to the submirror of the optical antenna. As a result, the size of the alignment adjusting system for use in the optical system in the optical transceiver of the present invention can be made smaller and the weight thereof can be made smaller than those of the conventional apparatuses, and further the present invention is capable of adjusting arrangement of the optical system located from the optical transceiver through the optical coupling or connection means to the submirror or the main mirror of the optical antenna with a higher accuracy. The provision of the alignment adjusting system allows the main mirror and the submirror to be made of light-weight metal materials each having a relatively smaller specific gravity and a relatively larger thermal conductivity, such as Al, Mg, Be or the like. Accordingly, the weight of the satellite in which the optical transceiver is provided can be advantageously and remarkably reduced.

By the arrangement of the above-mentioned preferred embodiment, when the reflection mirror for return-reflecting a beam of transmitting laser light is provided in the main mirror, the deviation amount of the beam of transmitting light from the optical axis of the optical system can be corrected so that the optical axis coincides with that of the beam of received light, over the optical system from the optical transceiver through the optical coupling or connection means to the submirror and the main mirror of the optical antenna. On the other hand, when the reflection mirror for return-reflecting a beam of transmitting light is provided in the submirror, the deviation amount of the beam of transmitting laser light from the optical axis of the optical system can be corrected so that the optical axis of the beam of transmitting light coincides with that of the beam of received light, over the optical system from the optical transceiver through the optical coupling or connection means to the submirror of the optical antenna. Accordingly, the size of the alignment adjusting system for use in the optical system in the optical transceiver of the present invention can be made smaller and the weight thereof can be made smaller than those of the conventional apparatuses, and further the present

invention is capable of adjusting arrangement of the optical system from the optical transceiver through the optical coupling or connection means to the submirror or the main mirror of the optical antenna with a higher accuracy.

5 Claims

1. An alignment adjusting system for use in an optical system in an optical transceiver, comprising:

10 an optical antenna (10) having a main mirror (1a) and a submirror (2), both of which being provided around an optical axis (CL) of said optical antenna (10) and away from each other by a predetermined interval, said optical antenna (10) transmitting a beam of transmitting light outputted from said optical transceiver to an optical antenna of a destination station after sequentially reflecting said beam of transmitting light by said submirror (2) and said main mirror (1a),

15 an optical coupling means (4, 11 to 15) for optically coupling said optical antenna (10) to said optical transceiver, first detection means (30, 31) for detecting a defocusing amount of said beam of transmitting light in said optical antenna (10),

20 first moving means (2d) for controlling the focusing of said beam of transmitting light,

first control means (20) for controlling said first moving means (2d) in response to a defocusing amount of said beam of transmitting light in said optical antenna (10) which is detected by said first detection means (30, 31), so that the defocusing amount of said beam of transmitting light becomes substantially zero,

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characterized by

a return-reflection mirror (1b) for return-reflecting a part of said beam of transmitting light, said return-reflection mirror (1b) being provided in either one of said main mirror (1a) and said submirror (2),

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said first detection means (30, 31) detecting the defocusing amount in response to said beam of transmitting light return-reflected by said return-reflection mirror (1b), and

35 said first moving means (2d) moving said submirror (2) in a direction parallel to the optical axis (CL) of said optical antenna (10).

2. The alignment adjusting system as claimed in Claim 1,

40 wherein said optical antenna (10) sequentially reflects a beam of received light received from said optical antenna (10) of said destination station by said main mirror (1a) and said submirror (2), and thereafter, outputs said beam of reflected light to said optical transceiver through said optical coupling means (4, 11 to 15); and

said alignment adjusting system further comprising:

45 second detection means (32, 33) for detecting a deviation amount of said beam of transmitting light from the optical axis (CL) of said optical antenna (10), in response to said beam of transmitting light return-reflected by said return-reflection mirror (1b);

50 third detection means (32, 33) for detecting a deviation amount of said beam of received light from the optical axis (CL) of said optical antenna (10) in response to said beam of received light reflected by said submirror (2);

second moving means (15) for moving the optical axis of said beam of transmitting light transmitting in said optical coupling means (4, 11 to 15), said second moving means (15) being provided in said optical coupling means (4, 11 to 15); and

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second control means (20) for controlling said second moving means (15) so that the deviation amount of said beam of transmitting light from the optical axis (CL) of said optical antenna (10) coincides with the deviation amount of said beam of received light from the optical axis (CL) of said optical antenna (10), in response to

the deviation amount of said beam of transmitting light from the optical axis (CL) of said optical antenna (10) which is detected by said second detection means (32, 33) and the deviation amount of said beam of received light from the optical axis (CL) of said optical antenna which is detected by said third detection means (32, 33).

5 3. The alignment adjusting system as claimed in Claim 1 or 2,

wherein said main mirror (1a) is either one of a ring-shaped concave parabolic mirror and a ring-shaped concave nearly-parabolic hyperbolic mirror;

10 said return-reflection mirror (1b) is either one of a ring-shaped concave spherical mirror and a ring-shaped concave nearly-spherical elliptical mirror, said return-reflection mirror (1b) being formed integrally together with said main mirror (1a) and concentrically with said main mirror (1a) around the optical axis (CL) of said optical antenna (10); and

15 said main mirror (1a) and said return-reflection mirror (1b) are arranged so that a focal point (Fp) of said main mirror (1a) coincides with the center (Rc) of curvature of said return-reflection mirror (1b).

4. The alignment adjusting system as claimed in Claim 3,

wherein said main mirror (1a) is provided on an outer periphery of a ring-shaped body, while said return-reflection mirror (1b) is provided on an inner periphery of said ring-shaped body, and

20 said return-reflection mirror (1b) has an optical through hole (1h) for passing said beam of transmitting light and said beam of received light therethrough, said optical through hole (1h) having a center coinciding with the optical axis (CL) of said optical antenna (10), said optical through hole (1h) being formed so as to be concentric with said main mirror (1a) around the optical axis (CL) of said optical antenna (10).

25 5. The alignment adjusting system as claimed in Claim 1 or 2,

wherein said submirror (2) is a convex hyperbolic mirror, and

30 said return-reflection mirror (1b) is either one of a concave spherical mirror and a concave nearly-spherical elliptical mirror which is formed integrally and concentrically with said submirror (2) around the optical axis (CL) of said optical antenna (10).

Patentansprüche

35 1. Ausrichtungseinstellsystem zur Verwendung in einem optischen System eines optischen Sendeempfängers, mit:

40 - einer optischen Antenne (10) mit einem Hauptspiegel (1a) und einem Unterspiegel (2), die jeweils um eine optische Achse (CL) der optischen Antenne (10) herum und um eine vorbestimmte Entfernung voneinander beabstandet angeordnet sind, wobei die optische Antenne (10) einen von dem optischen Sendeempfänger ausgegebenen Sendelichtstrahl an eine optische Antenne einer Zielstation sendet, nachdem der Sendelichtstrahl nacheinander von dem Unterspiegel (2) und dem Hauptspiegel (1a) reflektiert wurde,

45 - einer optischen Kopplungseinrichtung (4, 11 bis 15) zum optischen Koppeln der optischen Antenne (10) mit dem optischen Sendeempfänger,

- einer ersten Erkennungseinrichtung (30, 31) zum Erkennen eines Defokussierungsbetrags des Sendelichtstrahls in der optischen Antenne (10),

50 - einer ersten Bewegungseinrichtung (2d) zum Steuern der Fokussierung des Sendelichtstrahls,

- einer ersten Steuereinrichtung (20) zum Steuern der ersten Bewegungseinrichtung (2d) in Reaktion auf einen Defokussierungsbetrag des Sendelichtstrahls in der optischen Antenne (10), der von der ersten Erkennungseinrichtung (30, 31) erkannt wurde, so daß der Defokussierungsbetrag des Sendelichtstrahls im wesentlichen Null wird,

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gekennzeichnet durch

- einen Rückreflektionsspiegel (1b) zum Rückreflektieren eines Teils des Sendelichtstrahls, wobei der Rückre-

flektionsspiegel (1b) entweder in dem Hauptspiegel (1a) oder in dem Unterspiegel (2) vorgesehen ist,

- wobei die erste Erkennungseinrichtung (30, 31) den Defokussierungsbetrag in Reaktion auf den Sendelichtstrahl erkennt, der von dem Rückreflektionsspiegel (1b) zurückreflektiert wurde, und
 - wobei die erste Bewegungseinrichtung (2d) den Unterspiegel (2) in eine Richtung parallel zur optischen Achse (CL) der optischen Antenne (10) bewegt.
2. Ausrichtungseinstellungssystem nach Anspruch 1, bei dem die optische Antenne (10) einen von der optischen Antenne (10) der Zielstation empfangenen Empfangslichtstrahl nacheinander mit dem Hauptspiegel (1a) und dem Unterspiegel (2) reflektiert und anschließend den reflektierten Lichtstrahl an den optischen Sendeempfänger über die optische Kopplungseinrichtung 4, 11 bis 15) ausgibt; und wobei das Ausrichtungseinstellsystem ferner aufweist:
- eine zweite Erkennungseinrichtung (32, 33) zum Erkennen eines Betrags der Abweichung des Sendelichtstrahls von der optischen Achse (CL) der optischen Antenne (10) in Reaktion auf den von dem Rückreflektionsspiegel (1b) rückreflektierten Sendelichtstrahl;
 - eine dritte Erkennungseinrichtung (32, 33) zum Erkennen eines Betrags der Abweichung des empfangenen Lichtstrahls von der optischen Achse (CL) der optischen Antenne (10) in Reaktion auf den von dem Unterspiegel (2) reflektierten Empfangslichtstrahl;
 - eine zweite Bewegungseinrichtung (15) zum Bewegen der optischen Achse des in die optische Kopplungseinrichtung (4, 11 bis 15) gesendeten Sendelichtstrahls, wobei die zweite Bewegungseinrichtung (15) in der optischen Kopplungseinrichtung (4, 11 bis 15) angeordnet ist; und
 - eine zweite Steuereinrichtung (20) zum Steuern der zweiten Bewegungseinrichtung (15) derart, daß der Betrag der Abweichung des Sendelichtstrahls von der optischen Achse (CL) der optischen Antenne (10) mit dem Betrag der Abweichung des Empfangslichtstrahls von der optischen Achse (CL) der optischen Antenne (10) zusammenfällt, in Reaktion auf den von der zweiten Erkennungseinrichtung (32, 33) erkannten Betrag der Abweichung des Sendelichtstrahls von der optischen Achse (CL) der optischen Antenne (10) und in Reaktion auf den von der dritten Erkennungseinrichtung (32, 33) erkannten Betrag der Abweichung des Empfangslichtstrahls von der optischen Achse (CL) der optischen Antenne (10).
3. Ausrichtungseinstellsystem nach Anspruch 1 oder 2, bei dem der Hauptspiegel (1a) entweder ein ringförmiger konkaver Parabolspiegel oder ein ringförmiger nahezu parabolischer Hyperbolspiegel ist;
- wobei der Rückreflektionsspiegel (1b) entweder ein ringförmiger konkaver sphärischer Spiegel oder ein ringförmiger nahezu sphärischer elliptischer Spiegel ist, wobei der Rückreflektionsspiegel (1b) einstückig mit dem Hauptspiegel (1a) und konzentrisch mit dem Hauptspiegel (1a) um die optische Achse (CL) der optischen Antenne (10) ausgebildet ist; und
 - der Hauptspiegel (1a) und der Rückreflektionsspiegel (1b) derart angeordnet sind, daß ein Brennpunkt (Fp) des Hauptspiegels (1a) mit der Mitte (Fc) der Krümmung des Rückreflektionsspiegels (1b) zusammenfällt.
4. Ausrichtungseinstellsystem nach Anspruch 3, bei dem der Hauptspiegel (1a) auf dem Außenumfang eines ringförmigen Körpers vorgesehen ist, während der Rückreflektionsspiegel (1b) auf dem Innenumfang des ringförmigen Körpers vorgesehen ist, und
- der Rückreflektionsspiegel (1b) ein optisches Durchgangsloch (1h) zum Hindurchlassen des Sendelichtstrahls und des Empfangslichtstrahls aufweist, wobei das optische Durchgangsloch (1h) einen mit der optischen Achse (CL) der optischen Antenne (10) zusammenfallenden Mittelpunkt hat, wobei das optische Durchgangsloch (1h) derart ausgebildet ist, daß es mit dem Hauptspiegel (1a) um die optische Achse (CL) der optischen Antenne (10) konzentrisch ist.
5. Ausrichtungseinstellsystem nach Anspruch 1 oder 2, bei dem der Unterspiegel (2) ein konvexer Hyperbolspiegel ist, und

- der Rückreflektionsspiegel (1b) entweder ein konkaver sphärischer Spiegel oder ein konkaver nahezu sphärischer elliptischer Spiegel ist, der einstückig und konzentrisch mit dem Unterspiegel (2) um die optische Achse (CL) der optischen Antenne (10) ausgebildet ist.

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Revendications

1. Système de réglage d'alignement pour une utilisation dans un système optique dans un émetteur-récepteur optique, comprenant:

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une antenne optique (10) comportant un miroir principal (1a) et un sous-miroir (2) dont les deux sont prévus autour d'un axe optique (CL) de ladite antenne optique (10) et de manière à être séparés l'un de l'autre d'un intervalle prédéterminé, ladite antenne optique (10) transmettant un faisceau de lumière de transmission émis en sortie depuis ledit émetteur-récepteur optique sur une antenne optique d'une station de destination après réflexion séquentielle dudit faisceau de lumière de transmission par ledit sous-miroir (2) et par ledit miroir principal (1a) ;

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un moyen de couplage optique (4; 11 à 15) pour coupler optiquement ladite antenne optique (10) audit émetteur-récepteur optique ;

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un premier moyen de détection (30, 31) pour détecter une valeur de défocalisation dudit faisceau de lumière de transmission dans ladite antenne optique (10) ;

un premier moyen de déplacement (2d) pour commander la focalisation dudit faisceau de lumière de transmission ;

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un premier moyen de commande (20) pour commander ledit premier moyen de déplacement (2d) en réponse à une valeur de défocalisation dudit faisceau de lumière de transmission dans ladite antenne optique (10) qui est détectée par ledit premier moyen de détection (30, 31) de telle sorte que la valeur de défocalisation dudit faisceau de lumière de transmission devienne sensiblement égale à zéro,

caractérisé par :

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un miroir de réflexion en retour (1b) pour réfléchir en retour une partie dudit faisceau de lumière de transmission, ledit miroir de réflexion en retour (1b) étant prévu dans soit ledit miroir principal (1a), soit ledit sous-miroir (2) ;

ledit premier moyen de détection (30, 31) détectant la valeur de défocalisation en réponse audit faisceau de lumière de transmission réfléchi en retour par ledit miroir de réflexion en retour (1b); et

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ledit premier moyen de déplacement (2d) déplaçant ledit sous-miroir (2) suivant une direction parallèle à l'axe optique (CL) de ladite antenne optique (10).

2. Système de réglage d'alignement selon la revendication 1, dans lequel ladite antenne optique (10) réfléchit séquentiellement un faisceau de lumière reçue qui est reçu depuis ladite antenne optique (10) de ladite station de destination par ledit miroir principal (1a) et par ledit sous-miroir (2) puis émet en sortie depuis ledit faisceau de lumière réfléchi sur ledit émetteur-récepteur optique par l'intermédiaire dudit moyen de couplage optique (4, 11 à 15) ; et

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ledit système de réglage d'alignement comprenant en outre :

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un second moyen de détection (32, 33) pour détecter une valeur de déviation dudit faisceau de lumière de transmission par rapport à l'axe optique (CL) de ladite antenne optique (10) en réponse audit faisceau de lumière de transmission réfléchi en retour par ledit miroir de réflexion en retour (1b) ;

un troisième moyen de détection (32, 33) pour détecter une valeur de déviation dudit faisceau de lumière reçue par rapport à l'axe optique (CL) de ladite antenne optique (10) en réponse audit faisceau de lumière reçue réfléchi par ledit sous-miroir (2) ;

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un second moyen de déplacement (15) pour déplacer l'axe optique dudit faisceau de lumière de transmission qui est transmis dans ledit moyen de couplage optique (4, 11 à 15), ledit second moyen de déplacement (15) étant prévu dans ledit moyen de couplage optique (4, 11 à 15) ; et

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un second moyen de commande (20) pour commander ledit second moyen de déplacement (15) de telle sorte que la valeur de déviation dudit faisceau de lumière de transmission par rapport à l'axe optique (CL) de ladite antenne optique (10) coïncide avec la valeur de déviation dudit faisceau de lumière reçue par rapport à l'axe optique (CL) de ladite antenne optique (10) en réponse à la valeur de déviation dudit faisceau de lumière de transmission par rapport à l'axe optique (CL) de ladite antenne optique (10) qui est détectée par ledit second

moyen de détection (32, 33) et à la valeur de déviation dudit faisceau de lumière reçue par rapport à l'axe optique (CL) de ladite antenne optique qui est détectée par ledit troisième moyen de détection (32, 33).

3. Système de réglage d'alignement selon la revendication 1 ou 2, dans lequel :

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ledit miroir principal (1a) est soit un miroir parabolique concave en forme d'anneau, soit un miroir hyperbolique pratiquement parabolique concave en forme d'anneau ;

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ledit miroir de réflexion en retour (1b) est soit un miroir sphérique concave en forme d'anneau, soit un miroir elliptique pratiquement sphérique concave en forme d'anneau, ledit miroir de réflexion en retour (1b) étant formé d'un seul tenant avec ledit miroir principal (1a) et concentriquement avec ledit miroir principal (1a) autour de l'axe optique (CL) de ladite antenne optique (10) ; et

ledit miroir principal (1a) et ledit miroir de réflexion en retour (1b) sont agencés de telle sorte qu'un point focal (Fp) dudit miroir principal (1a) coïncide avec le centre (Rc) de courbure dudit miroir de réflexion en retour (1b).

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4. Système de réglage d'alignement selon la revendication 3, dans lequel :

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ledit miroir principal (1a) est prévu sur une périphérie externe d'un corps en forme d'anneau tandis que ledit miroir de réflexion en retour (1b) est prévu sur une périphérie interne dudit corps en forme d'anneau ; et ledit miroir de réflexion en retour (1b) comporte un trou de passage optique (1h) pour laisser passer ledit faisceau de lumière de transmission et ledit faisceau de lumière reçue au travers, ledit trou de passage optique (1h) comportant un centre qui coïncide avec l'axe optique (CL) de ladite antenne optique (10), ledit trou de passage optique (1h) étant formé de manière à être concentrique audit miroir principal (1a) autour de l'axe optique (CL) de ladite antenne optique (10).

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5. Système de réglage d'alignement selon la revendication 1 ou 2, dans lequel :

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ledit sous-miroir (2) est un miroir hyperbolique convexe ; et ledit miroir de réflexion en retour (1b) est soit un miroir sphérique concave, soit un miroir elliptique pratiquement sphérique concave qui est formé d'un seul tenant avec ledit sous-miroir (2) et de façon concentrique à celui-ci autour de l'axe optique (CL) de ladite antenne optique (10).

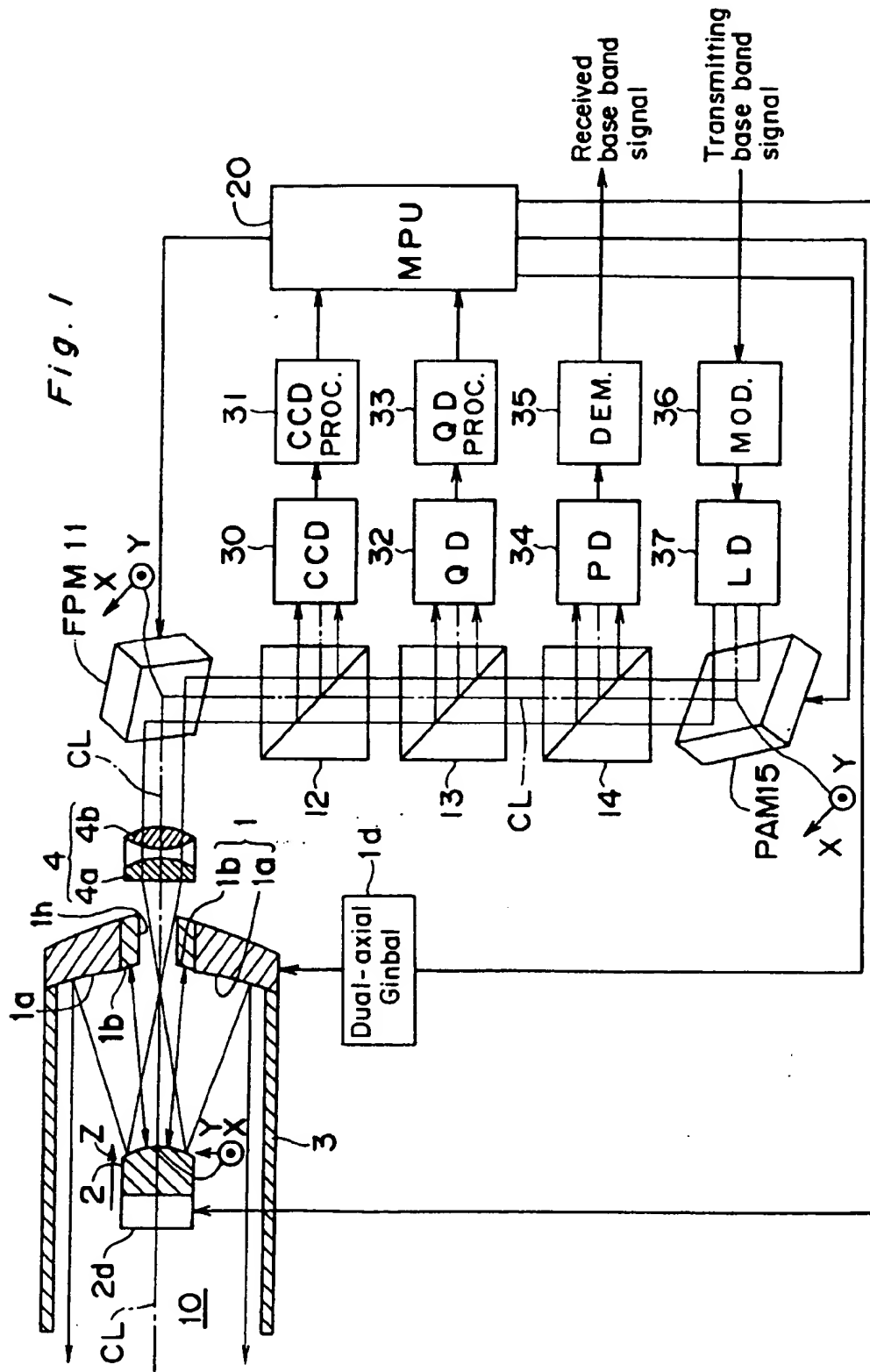
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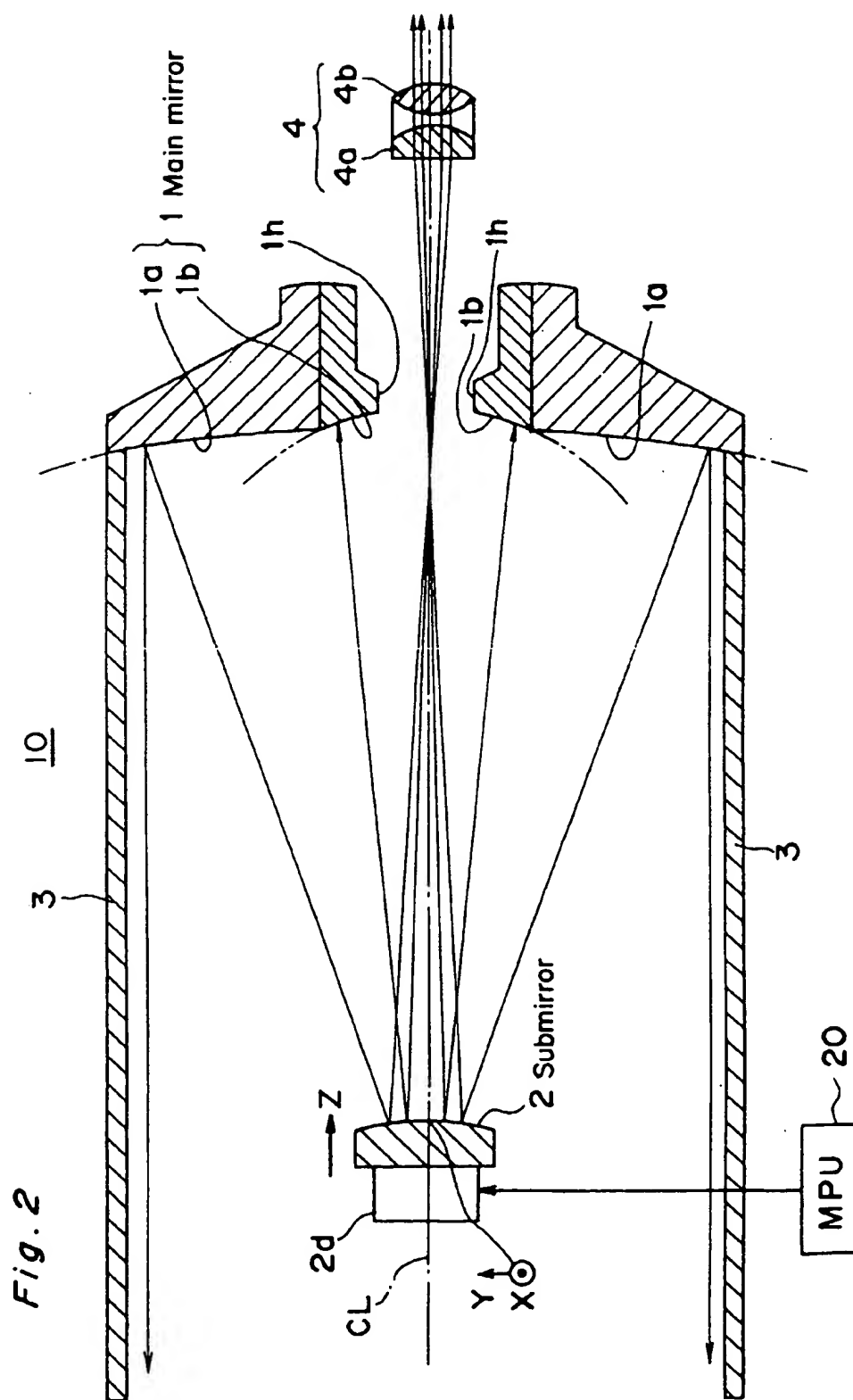


Fig.3

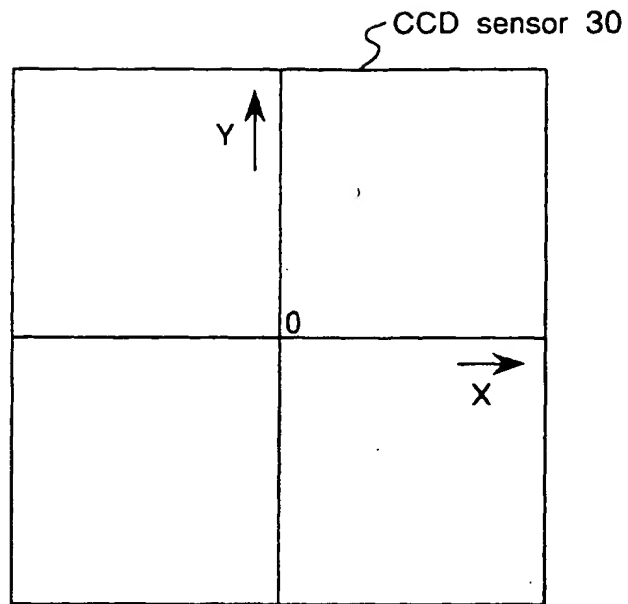


Fig.4

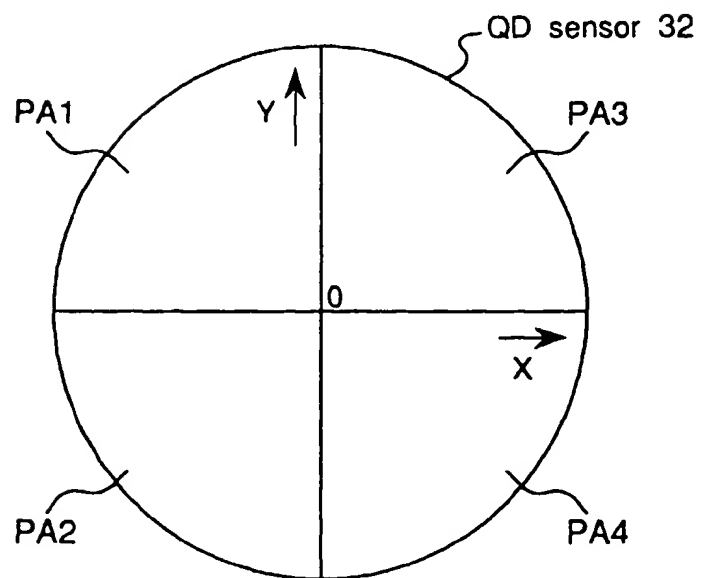


Fig. 5

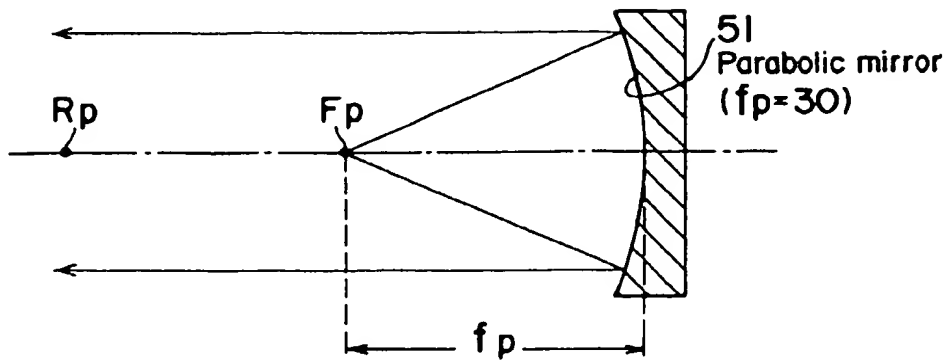


Fig. 6

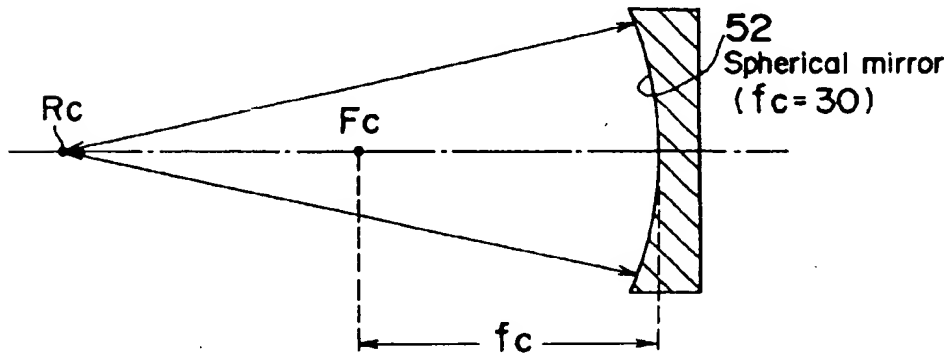


Fig. 7

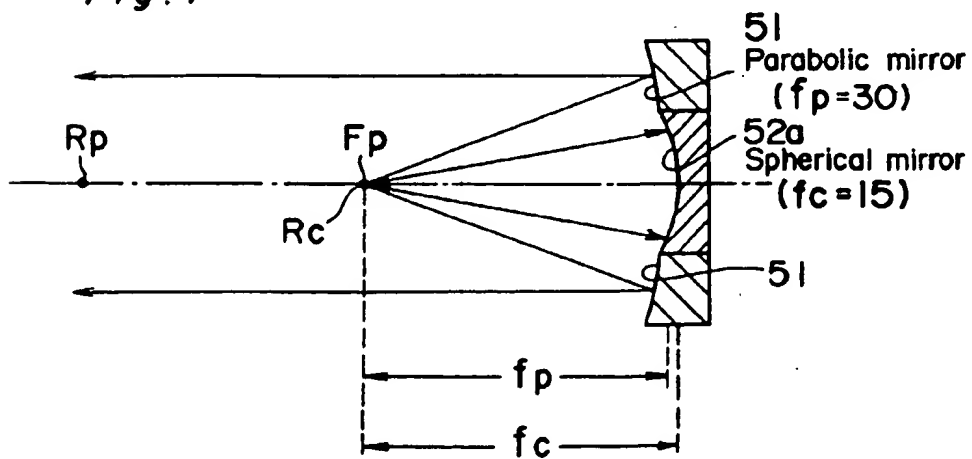


Fig.8

